Heavy Quark Detection With A Forward Silicon Micro-vertex Detector at PHENIX

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Abstract. Intriguing evidence that a new state of matter, the quark-gluon plasma (QGP), is formed in collisions of ultra-relativistic heavy ions has been presented during the past year by physicists working at the Relativistic Heavy Ion Collider (RHIC) at BNL. We are developing a unique experimental capability at RHIC for the direct identification of heavy quarks, which will be used to accurately determine the properties of this new state of matter. We will construct a silicon micro-vertex detector (SVD) covering the forward collision region, which will provide an excellent measurement of charm quark decays in the high multiplicity environment of nuclear collisions. Based upon electronics developed for the BTeV experiment, the SVD will cover one quarter of a PHENIX muon arm. Internal LANL funding will cover the construction costs.

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INTRODUCTION

A compelling case for the production of a quark-gluon plasma at RHIC, based upon measurements of light quarks, has developed over the last year. Evidence includes the observation of large energy loss of jets in the plasma, consistent with jet-quenching predictions, together with an apparent elliptic flow of produced particles, in good agreement with hydrodynamic models of the QGP. Surprisingly, the plasma appears to have the properties of a strongly interacting liquid, rather than the expected weakly interacting plasma. Unfortunately, very little more is known about the detailed properties of the QGP.

Heavy quarks (*charm* and *beauty*) are widely recognized as the cleanest probes in the laboratory quest for the QGP and their analysis is the vital next step to clinch its discovery. Use of such heavy particles as test charges in the plasma may be compared to the study of Brownian motion of a dust particle in a fluid - historically the first direct probe of the atomic properties of matter. At present, none of the existing experiments at the RHIC facility are capable of directly identifying heavy quarks.

The primary goal of this project is to make the most accurate measurement of the properties of the QGP, using heavy quarks as probes. We plan to construct a silicon micro-vertex detector (SVD) with state-of-the-art position resolution, speed and low power consumption, based upon custom readout electronics originally developed for the BTeV experiment. A closely integrated theoretical effort will develop the tools necessary for the full interpretation of the new heavy quark data, including state-of-the-art perturbative QCD, lattice QCD and non-equilibrium field theory calculations.

DETECTION OF HEAVY QUARKS WITH THE SVD

Charm and beauty particles can be cleanly identified by measuring their lifetimes. These are ~1 ps, which translates into a decay distance of ~1 mm at forward angles at RHIC. We will use the SVD to precisely measure the decay distance, together with a PHENIX muon arm to identify the decay muon and record its momentum, as shown in Figure 1. The two heavy ions intersect at the indicated collision point, where a charm particle (D^+) is produced. The D^+ then travels a certain distance where it decays to a muon (μ^+). The four planes of the SVD precisely record the trajectory of the muon. Using this trajectory, the distance of closest approach (DCA) of the muon to the collision point is determined. The decay distance and hence the lifetime of the heavy quark is proportional to the DCA. Backgrounds from processes other than heavy quark decays are eliminated by rejecting events with too short or too long a lifetime.

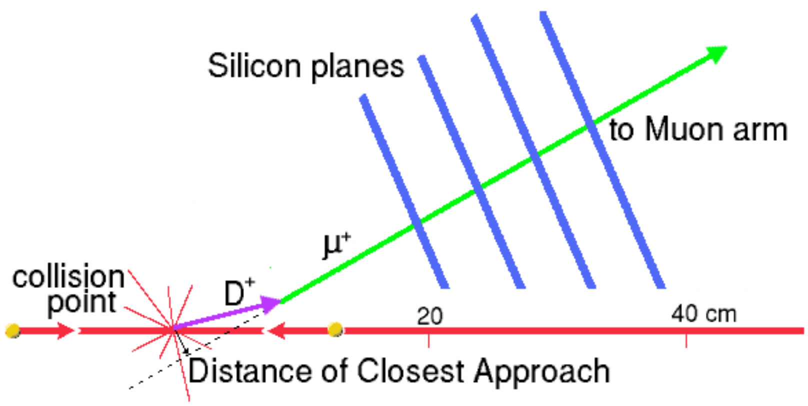

FIGURE 1. Detection of charm particle (D^+) decay using the SVD.

DESIGN OF THE SVD

The optimal technique for very high-resolution particle detection is the use of finely segmented silicon detectors. Consideration of factors such as occupancy, radiation dose, power, cost and availability led us to a design with detectors composed of 50 μm by 400 μm pixels. The SVD consists of two sectors (one of which is shown in Figure 2), consisting of 4 detector planes each and covers one eighth of a PHENIX muon spectrometer. Each silicon plane contains an array of pixel detectors that are bump-bonded to FPIX2 readout chips.

The planes are composed of 24 detector modules covering the front and back of a support/cooling structure, providing a uniform acceptance across the surface. The pixels are oriented with the fine pitch located in the radial (vertical) direction and coarse in phi (horizontal). Thus, each plane of the SVD has an excellent position resolution of ≤14 μm in the radial direction and a good resolution of 120 μm in the phi coordinate. A total of 192 modules are required, corresponding to $4.3*10^6$ pixels. The estimated power consumption is only 390 W (90 μW per FPIX2 channel). Single-phase liquid cooling will remove the heat from each SVD plane via a thermal pyrolytic graphite substrate.

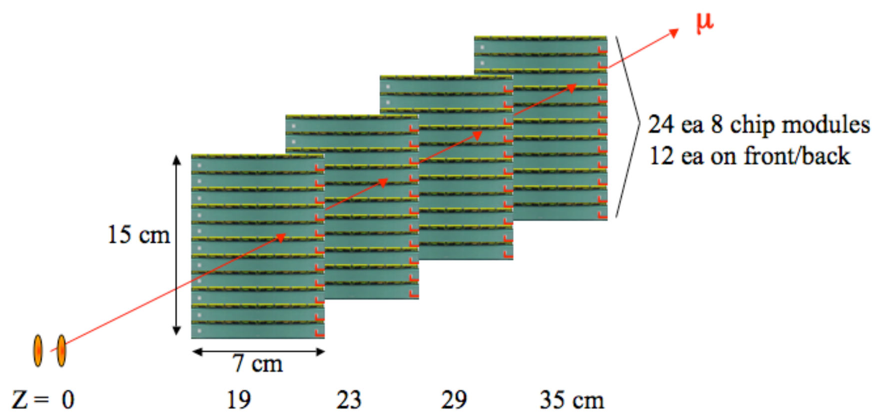

FIGURE 2. Layout of one sector of the SVD, consisting of four silicon planes. The locations shown for the planes are in the z-direction, along the beam axis. Pixels are 50 μm high by 400 μm long.

Each detector module consists of a BTeV pixel sensor (6.4 mm high by 70 mm long), flip-chip assembled to 8 FPIX2 chips. This hybrid pixel sensor is an advanced moderated p-spray device with very high radiation tolerance, similar to that used by the ATLAS experiment. The FPIX2 readout chip, implemented in radiation tolerant 0.25 μm low-power CMOS, utilizes a high-speed (840 Mbit/sec) data-driven architecture to read out the hit pixels. The FPIX2 chips are wire-bonded to a high density interconnect constructed of multi-layer Kapton cable. The data are output on parallel LVDS lines, which travel over 10 m cables to an FPGA-based controller board, which serves as an interface to the PHENIX data acquisition system.

PERFORMANCE SIMULATIONS

We have studied the performance of the SVD using the PYTHIA and HIJING event generators, together with PISA (the PHENIX implementation of GEANT). The z-vertex resolution for a 5 GeV/c muon is ~190 μm, decreasing to ~130 μm at 10 GeV/c. The corresponding DCA resolutions are a factor of 2.5 smaller. Backgrounds from long-lived pion and kaon decays are easily removed by a 1 cm cut on the maximum DCA. At large momentum, there is an additional background from prompt pions that we expect can be removed by a minimum DCA cut; this is presently under study. The signal-to-background ratio for muons from charm decays improves by a factor of ~10 after the application of a vertex cut, providing for a clean measurement of charm over a large range of muon transverse momenta. Rate estimates for heavy quark semi-leptonic decays indicate that $\sim 10^7$ charm and $\sim 10^4$ beauty decays could be recorded during a typical Au+Au run at RHIC.

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